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Coupled regional climate and hydrology modelling at the catchment scale

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1. Introduction

More and more regional climate models are being applied at scales down to even a few kilometres. At these scales the complex interactions between the atmosphere, the land surface, and the subsurface hydrology are crucial for understanding climate feedbacks at the regional to local scales. Many of the current regional climate models, however, have only a limited capability to represent all the parts of the terrestrial water cycle. This is particular true for the interactions between surface water and groundwater dependent ecosystems and surface water and groundwater resources, which in many cases have been shown to play a critical role in the regional earth system.

In the present study we investigate a dynamically coupled version of the DMI-HIRHAM (Christensen et al., 2006) regional climate model and a comprehensive distributed hydrological modelling system, MIKE SHE [Højbjerg et al., 2013], nested inside the regional climate model. A particular challenge in coupling a climate model to a hydrological model resides in in the vastly different philosophies expressed by such codes. While regional climate models generally implement primary physical equations, hydrological models typically are heavily calibrated codes. Likewise, temporal and spatial resolutions are often quite different. Lastly, present versions of MIKE SHE are native only to the Microsoft Windows operating system, necessitating the development of a novel cross-platform model interface based on open-source OpenMI technology (Gregersen et al., 2005 and Gregersen et al., 2007).

The coupled model has been evaluated for a groundwater-dominated catchment in the western part of Denmark, Skjern River, covering approx. 2500 km2 with a grid spacing of 500 m, which is embedded within a 4000 x 2800 km regional climate modelling domain with a horizontal resolution of approx. 11 km (Figure 1). The setup has proven stable and has been used for simulations of several years.

Inside the shared model domains the coupled model enables two-way interactions between the atmosphere and the groundwater via the river and land surface through an energy-based land surface model (SWET) (Overgaard, 2005). In this manner the simple land surface model embedded in DMI-HIRHAM is effectively replaced by the superior land surface component of the combined MIKE SHE/SWET model, which includes a wider range of

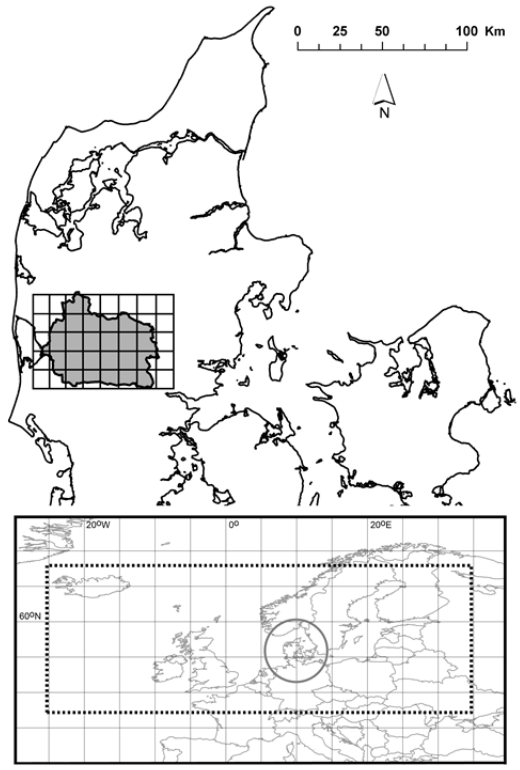

Figure 1. HIRHAM regional climate model domain and the Skjern River catchment location within Denmark also showing the HIRHAM grid cells.

processes at the land surface and distributed three-dimensional subsurface flows as well as higher temporal and spatial resolution. Outside the shared domain DMI-HIRHAM utilizes its own embedded land surface model; however, the model nesting makes it possible to detect substantial feedbacks from the improved surface/subsurface hydrology to the atmosphere even outside the shared domain.

2. Studies

The task of individually calibrating and preparing each of the two modelling systems was performed in two studies preceding the coupled simulations (Larsen et al., 2013a and Larsen et al., *in preparation*). The coupled simulations were assessed in two separate studies:

Through 26 simulations (see example in Figure 2), the first study investigates the overall performance and feasibility of the coupled setup as compared to uncoupled simulations and further investigated the

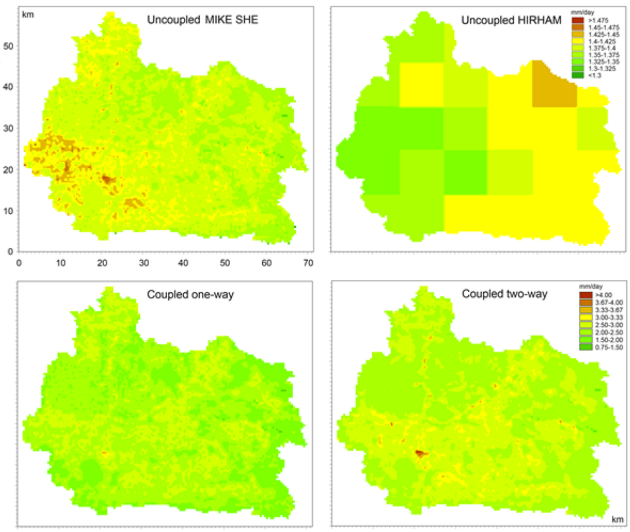

Figure 2. The simulated spatial distribution of mean daily evapotranspiration for the period June 5-11, 2009, from MIKE SHE alone (observed forcing data), HIRHAM alone, coupled one-way (MIKE SHE simulation with HIRHAM forcing data and no feedback to HIRHAM) and fully two-way coupled with dynamic feedback.

influence of the data transfer interval between the

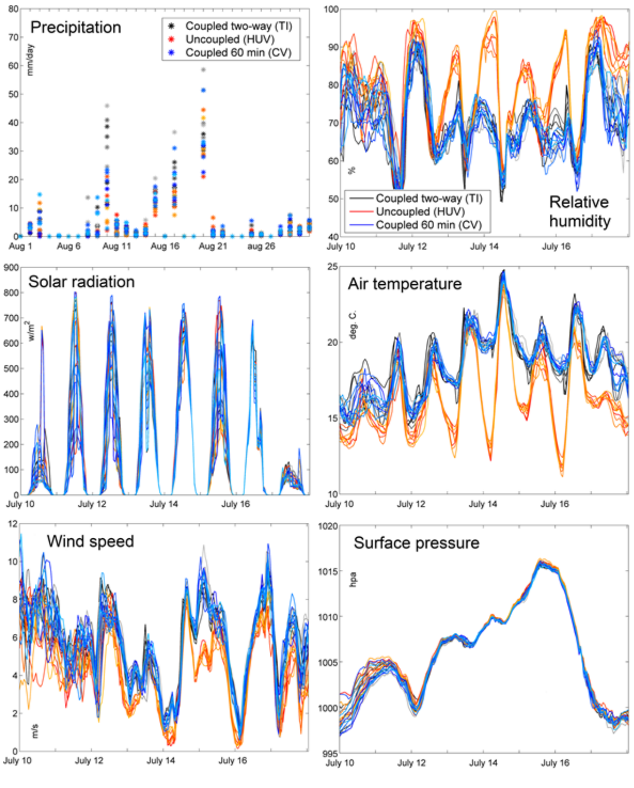

Figure 3. The six climatic variables used in the assessment of the coupled setup for the 10-18 July period, 2009, (precipitation is 1-31 August). The TI, HUV and CV runs each represent groups of eight simulations varying the data transfer interval of 12-120 minutes (TI), assessing HIRHAM uncoupled variability (HUV) as well as fully coupled variability (CV).

models and model variability (Larsen et al. 2013b). The results are tested against ten variables: Six atmospheric observation data variables (precipitation, wind speed, air temperature, surface pressure, global radiation and relative humidity) (Figure 3) as well as four ground/surface energy flux and water balance variables (latent-,sensible- and soil- heat fluxes as well as river discharge). Using varied data transfer rates between the models of 12-120 min the coupled results show improvements with an increase in data transfer frequency. In general however, the coupled performance is poorer compared to the uncoupled. This is explained by the calibration and parameterization of each model prior to the coupling. A perspective for future experiments therefore includes coupled model calibration and further experiments are suggested to investigate performance on larger scales and in other regions.

The anticipated improvement in the reproduction of land-surface-atmosphere flux exchanges, temporally and geographically, from the MIKE SHE/SWET model as compared to HIRHAM is investigated in the other study focusing on periods of non-normal weather. Periods of more pronounced drought/rainfall and temperature minima and maxima were therefore investigated.

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